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USING LINEAR SHAPED CHARGE(LSC) TO FORM BAILOUT EMERGENCY EXIT

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Abstract

Bailout is an important escape method to the crewmember of military aircraft. Bailout emergency exit directly determines the success rate of escape. The time is one of important factor for the emergency evacuation of aircraft. Using linear shaped charge (LSC) to cut the aircraft fuselage to form the emergency exit can be saved the ready time of evacuation and enhanced the evacuation success rate. The rapid decompression, construct distortion, construct intension and reverse impact of explosive to aircraft must be consider when using LSC to cut aircraft fuselage for bailout in higher flight altitude. Because exists of the frames and ribs, the LSC must bend to avoid these construct which will reduce the cutting effects of LSC. The plenty of experiment were carried out to validate this phenomenon. The test result show that if the distance between the curving LSC and frame was controlled in 2 millimeter and 8 millimeter, and the distance between the curving LSC and rib was less than 2 millimeter, the request of cutting stringer and frame can be satisfied.

1 Introduction

Bailout was an only selection for pilot when the aircraft is in the air in case of emergency cannot normally land and the aircraft must be abandoned. Under normal circumstances, the aircraft door or hatch was used as emergency exit to bailout, but that there are two negative aspects: First, the time of evacuation is longer, because it takes the time to open the door or hatch. The second is that the non-hydraulic door or hatch cannot be opened manually under the influence of the aerodynamic load even in the case of complete relief pressure. By preliminary calculations, the aerodynamic load on the after boarding gate of a typical aircraft in level flight is about 200kg and the load point at the center of the gate. The load direction is point to the gate outside the normal direction. If the door is non-hydraulic actuator, the door under this load cannot open by manually.

Explosive cutting technology has been widely used in the field of aviation rescue, such as in B-2, F-111, C-17, MD-11, C-97 and the other aircraft have been applied for clear channel or form an emergency ejection export[1]. The technology of explosive cutting was also used in the ARJ-21 aircraft flight test phase, the connecting mechanism of boarding gate was cut and the gate was jettison to cabin using powder. The F-10 aircraft use the microburst cord blasting hatch glass [2,3,7,8]. Compared with other method of form emergency exit, the explosive cutting technology has obvious advantages: saving preparation time, improve the success rate of rescue. When used in an emergency evacuation, and also avoid situations that the door cannot open because of the structural deformation affecting evacuation occurred [4]. In addition, compared with the door structure, explosive cutting technology can also simplify the complex structure and reduce the weight of the aircraft.

Compared with fractured canopy glass using mild detonating cord (MDC), the cutting fuselage construct using linear shaped charge (LSC) has greater difficulty because of the exits of stringers and frames. The shock environments produced by LSCs can cause damage and even failure of the surrounding attached structure, as well as other components mounted upon that structure. Therefore, structural deformation and strength, explosive reverse impact and other shock effect must be consider when use LSC cut aircraft construct to form bailout emergency exit.

2 Explosive Cutting Technology Principles

LSC uses the Munroe Effect to cut metal. C.E. Munroe, a U.S. chemist, discovered the so-called Munroe Effect, stated as follows: "The Munroe Effect is the reinforcement of shock waves in a hollow charge, concentrating the effect of the explosion along the axis of the charge" [9]. LSC cutting ability is a function of detonation rate and sheath material characteristics. Cutting ability is affected by hardness, strength, and density of the material being cut.

Linear shaped charges are composed of a seamless metal sheath containing an explosive core. A "V" configuration is used for all modern LSCs. The continuous liner and explosive produce a linear cutting action. The Munroe Effect is enhanced by careful control of charge dimensions and configuration. Figure 1 is a cross sectional view of an LSC. Figure 2 illustrate how an LSC cutting a metal.

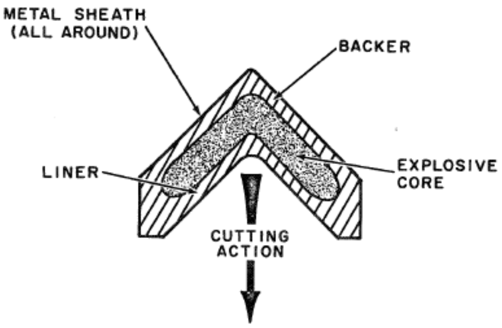
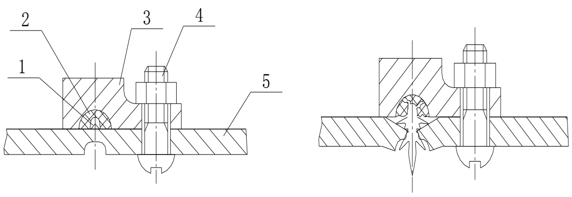


Fig.1 LSC cross-sectional



1-LSC, 2-Rubber Sheath, 3-Metal Shield, 4-Compression Screw 5-Cutting Target

Fig.2 LSC cutting action

3 Design Project

3.1 Cut Area

According to the request of bailout in the air, the area of 850mm×1200mm must be cut to form bailout emergency exit. Therefore, there are total thirteen stringers and one frame was cut according to the structural features of a typical aircraft. Figure 3 illustrate the components of system and cutting area.

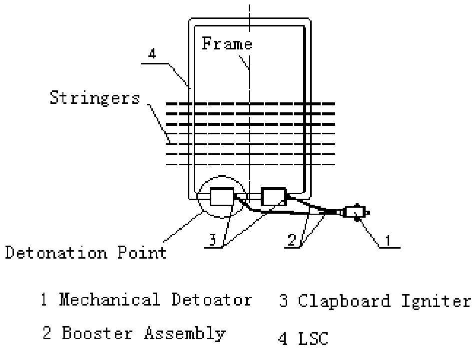


Fig.3 System Components and Cut Area

3.2 Rapid Decompression Calculations

Rapid or explosive decompression must be consider when bailout at high altitude. Rapid decompression is not at all dangerous to human conditions which depends on the two factors: 1) the time of decompression; 2) body relative expansion value K[5] as follow:

$$K = \frac{P_c - 6266}{P_h - 6266}$$

Where P_c is the cabin pressure before decompression, P_h is the external or ambient pressure, the constants 6266 is the water vapor pressure when the normal human body temperatures is 37 Celsius. All of parameters unit is Pascal. The time of decompression can be calculated using the follow formula.

$$\tau_T = \frac{V}{A\sqrt{RT_c}} \varphi(\frac{P_c}{P_h})$$

Where V is the cabin volume, the unit is cubic meter; A is section area of broken hole, the unit is square meter; R is the gas constants; T_c is the cabin temperature, the unit is kelvin.

If the time of explosive decompression less than 0.02~0.06 seconds and the relative expansion value K is not greater than 2.5~3, the explosive decompression is no danger to humans. If the time of explosive decompression is greater than 0.5~1 second, even relatively expansion value K is large, there is no danger to humans.

Decompression process of the lung is divided into three periods: 1) inertial period, the expansion of the lung did not happen yet and the lung volume was unchanged. The time of this period is about to 10 milliseconds. 2) Expansion period, the lung expansion to the status of total capacity. The absolute pressure of lung inside is rapidly decreased. According to the inertial period and the resonant frequency of chest and lung system, the minimum time of this period is 90 milliseconds under the sufficient pressure difference between inside and outside of the lung condition. 3) Expiratory phase is a large pulmonary gas discharge period. At the first and second period, the volume of discharge is very little and the decompression effect rely on exhaust gas can be negligible. At the third period, the lung volume gradually returned to normal from the maximum status and the inside pressure of lung is equilibrium with the outside world with the gas discharge.

According to the decompression process of lung and cabin pressure system, we can get the formula of calculation lung inside pressure difference as follow.

$$P_1 = \frac{P_0 V_0}{V_1}$$

Where P_1 is the lung pressure after decompression 100 milliseconds, P_0 is the cabin pressure before explosive cutting; V_0 is the initial volume of lung, V_1 is the lung volume after expansion.

The process of cabin decompression is supercritical flow at initial period and then change to subcritical flow. The gas mass outflow from the lung under the initial 100 milliseconds can be calculated by the follow formula.

$$M = \varphi\left(\frac{P_c}{P_h}\right)\rho v A \tau$$

Where $\varphi\left(\frac{P_c}{P_h}\right)$ is the characteristic parameter of decompression which is calibrated to the change of the flow state. v is the exit velocity of flow which can be calculation use the sonic formula, the unit is meter per second. τ is the time of explosive decompression, the unit is second. ρ is the air density.

The cabin pressure and the difference of lung pressure after decompression of 100 milliseconds can be calculation by the following formula.

$$P = \left(\frac{P_0 V}{RT_c} - M\right) RT_c / V$$

$$\Delta P = P_1 - P$$

Therefore, the pulmonary pressure peak at the different flight altitude can be calculated and the result as show in table 1.

Table.1 Pulmonary Pressure Peak at Different Altitude

No.	Altitude (m)	After 100ms Lung Inside Pressure/kPa	Cabin Pressure/kPa	Lung Difference Pressure/kPa
1	6500	52.872	45.081	7.791
2	6000	53.58	46.619	6.961
3	5500	55.67	49.87	5.8
4	4000	63.087	60.79	2.297

3.3 Structural Deformation

The shock environments produced by LSCs can cause damage and even failure of the surrounding attached structure, as well as other components mounted upon that structure, which could influence the evacuation of aircrew from aircraft. Therefore, the structural deformation of cut area was simulation use the finite element software. Figure 4 is the maximum deformation before explosive cutting, and figure 5 is the maximum deformation after explosive cutting.

The relative displacement of each node is shown in the table 2. Form the table data we can see that the relative displacement have both positive and negative along the three direction. The coordinate system used the aircraft global coordinate system. The origin is located at the aircraft head. The X axis is along the course and the positive is from head to tail. The Y axis is vertical direction and the positive is upward. The Z axis is along the aircraft lateral and the right is positive.

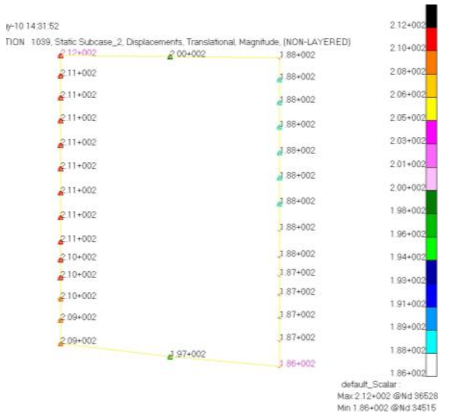


Fig.4 The Maximum Deformation Before Cut

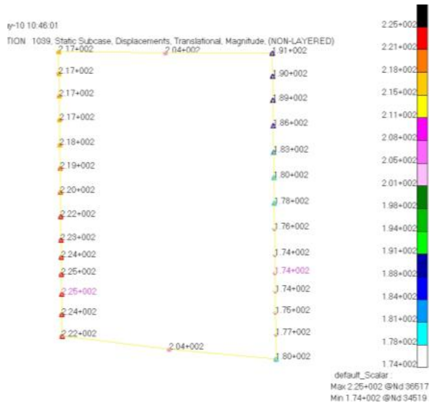


Fig.5 The Maximum Deformation After Cut

Through compared with the displacement of cut area each node before and after explosive cutting, the maximum displacement along the Y positive direction is 22.93 millimeter, and the maximum displacement along the negative direction is 12.63 millimeter. Compared with the value of cut area along vertical, the deformation displacement is smaller and can be neglected. The maximum positive displacement of Z is 14.38 millimeter and the maximum negative displacement is 11.39 millimeter. Although the cut areas will produce distortion along the aircraft lateral direction, the deformation displacement is very small and not enough to affect the evacuation of aircrew. The displacement along the course is very little.

Tab.2 Relative Displacement of Each Node

Node	Relative Dispalcement		
	ΔX	ΔY	ΔZ
34517	-1	-2.56	-12.53
34518	-0.96	-2.92	-13.98
34519	-0.93	-3.07	-14.38
34520	-0.88	-3.18	-14.03
34521	-0.76	-3.42	-12.38
34527	1.06	-12.63	10.98
34528	2.03	-12.75	11.39
36515	-3.43	20.49	2.49
36516	-2.44	21.01	3.42
36517	-1.82	21.16	3.36
36518	-1.06	21.09	2.45
36519	-0.36	21.01	1.23
36520	0.37	20.97	-0.29
36521	1.35	21.05	-2.66
36522	2.28	21.32	-5.16
36523	3.07	21.76	-7.52
36524	3.69	22.3	-9.51
36525	4.12	22.81	-11
36526	4.28	22.93	-11.43
36527	4.15	22.24	-10.57
36528	4.01	20.34	-8.24

According to the simulation result, structural deformation due to shock environment by LSC cannot influence the evacuation of aircrew.

2.4 Structural Strength Check

Except the structural deformation should consider, the structural strength surrounding the cut area must be checked to verify the structural is not damaged by the shock.

Structural strength check is related with the aircraft load and the load depending on the flight status. Taking into account the bailout is general used in level flight condition, the two calculation state was selected. The flight altitude of two states is 6000 meter, and Mach number is 0.3907 and 0.3797 respectively. The angle of attack is 12.95 and 7.75 degree respectively. Only Y direction to overload is 2.96 and -1.11 respectively. The calculation result as shown in table 3 and figure 6.

From the calculation result we can see that the structural strength around the cut area meet the request of the strength after explosive cutting under the calculation status. Although the selected calculation status cannot represent all of the emergency flight status, the calculation result is able to prove explosive cutting cannot cause aircraft structural damage based on the consideration of bailout almost carried out in the level flight.

Table 3 Strength Calculation Result

Structural Position	Condition	Load Type	Allowable Stress/MPa	Work Stress/MPa	Safety Margin
33-34Frame 31Stringer	1	Pull	392	29.54	12.2
34-35Frame 15Stringer	1	Push	-146.65	-34.19	3.29
16-17Stringers 33Frame	2	Pull	392	133.71	1.93
15-16Stringers 34Frame	2	Push	294	112.25	1.62
36-37Frame 13-12Stringer	2	Pull	392	64.83	5.04
33-34Frame 17-16Stringer	1	Push	49.3	19.8	1.49
36-37Frame 13-12Stringer	2	Shear	38.33	15.28	1.51
		Push and Shear			0.61

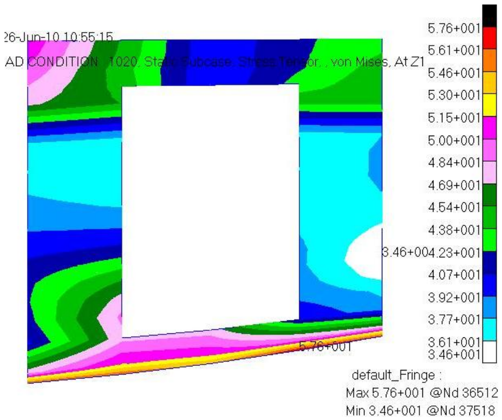


Fig.6 Surrounding Structural Equivalent Stress

3.5 Reverse Impact

When using explosive cutting technology to form an bailout emergency exit, the reverse impact produced by LSC explosive shock might affect the aircraft flight attitude, and resulting in uncontrollable aircraft attitude. Therefore, the reverse impact force of explosive shock was calculated according to the ground verification test data, as shown in table 4.

Because of the aircraft weight is greater than separate body, the impact force produced by the explosive shock cannot affect the aircraft attitude.

Table 4 Calculation Result

Test	T0(ms)		v（m/s）	m(kg)	F（N.m）	Fc(kN)
1	t1=1.04 t2=1.05 t3=1.08	Mean 1.06	4.85	7.8	37.8	35.7
2	t1=0.93	Mean 0.98	3.53	7.83	27.6	28.3

Note: T0 is the time from detonate to target separate;
V is the velocity of separate body;
m is the mass of separate body;
F is the impulse of separate;
Fc is the instantaneous force of fuselage.

4. Ground Test

The technical difficulties use LSC to cut fuselage structure is that the LSC must be bend to cross the frame and stringer which will reduce the cutting effects of LSC. In order to validate this phenomenon, the plenty of experiment were carried out. Figure 67 and Figure 8 shows the control range at install LSC. The test result show that if the distance between the bending LSC and frame was controlled in 2 millimeter and 8 millimeter, and the distance between the bending LSC and stringer was less than 2 millimeter, the request of cutting skin and frame can be satisfied.

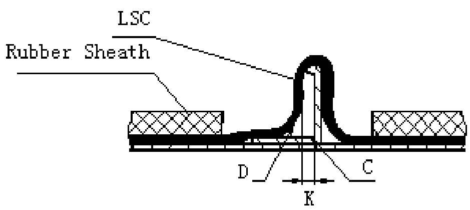


Fig.7 LSC Install on the Stringer

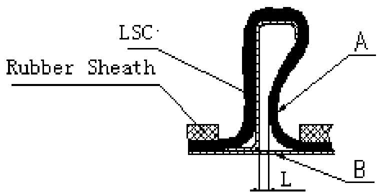


Fig.8 LSC Install on the Frame

After determin the installation clearance between LSC and fuselage structure, the full-size ground test was carried out. Figure 9 is a test result. The reverse impact on aircraft was measurement and calculation as shown in table 4. The result show that the reverse impact will not change the aircraft attitude and the structure was smoothly cut.

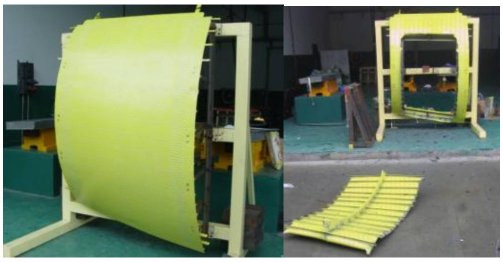


Fig.9 The Test Result

5. Conclusions

The design and test of aircraft bailout emergency exit device using LSC was discourse on this paper from rapid decompression, structural strength, structural deformation and explosive reverse impact. The research result and ground test provided evidence for the explosive cutting technology used in the aircraft.

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